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RESEARCH ON ORBITAL PLASMA: ELECTRODYNAMICS(ROPE)

Award NAS8-37108

FINAL REPORT

by Uri Samir

We analyzed selected samples of data from the DIFP probe. This probe is capable of deconvolving multiple, coincident ion streams that differ in flow direction and/or energy.

The focus of our specific effort was (at this stage) on the ion temperature enhancement in the wake of the satellite. Our conclusions provide new findings. Our results were examined vis-a-vis other measurements.

Enclosed is a copy of a paper now in final preparation to be submitted for publication to the Journal of Geophysical Research.

Ion Temperature enhancement in the wake of ionospheric spacecraft

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Abstract

Enhancements of the temperature of electrons in spacecraft plasma wakes have been reported for numerous cases [Samir and Wrenn, 1972; Troy et al., 1975; Oran et al., 1975) and this phenomenon has been discussed both empirically (Samir and Stone, 1986; Stone and Samir, 1986) and theoretically (Singh et al., 1987). However, very few measurements seem to have been made of the *ion* temperature within plasma wakes—possibly because the great majority of ion measurements were focussed on obtaining geophysical parameters and, hence, were confined to the region ahead of the spacecraft. Recently, however, an enhancement of the temperature of ions was discovered in data obtained in the wake of the Space Shuttle during the Spacelab-2 mission (Sorensen et al., 1997). At the time of that publication, this was the only known observation of this type. Herein, we report an additional case of ion temperature enhancement in a plasma wake. The data were taken during the Tethered Satellite System Reflight mission (TSS-1R) in the wake of the tethered satellite during passive (no current flow) operations. The measurements were obtained with the Differential Ion Flux Probe, or DIFP (Stone, 1977 and Stone et al., 1985).

Introduction

The interaction between a body and its neighboring space environment is an area of research that is of fundamental scientific importance and has well-known practical applications. The bodies concerned, either natural or artificial, can have a variety of properties; e.g., magnetized or non-magnetized and conducting or dielectric surfaces.

In the present study, we restrict ourselves to satellites that are not self-magnetized and orbit within the terrestrial ionosphere. Aspects of the interaction between a spacecraft and the ionosphere were studied throughout the past four decades. Among the early studies we cite Samir and Willmore (1965); Medved (1969); and Samir and Wrenn (1969). More detailed descriptions of various aspects of the interaction can be found in (Samir and Stone, 1986; Stone and Samir, 1986). Despite the long interest in this area of research, some basic physical questions remain unsolved.

Most studies were performed for highly rarefied, supersonic, sub-Alfvenic plasma flows. The bodies were typically unmagnetized with conducting surfaces. For this type of ionospheric interaction, the relevant ionic Mach number is about 5. Hence, the motion of the spacecraft is supersonic with respect to the ambient ions and highly sub-sonic with respect to the ambient electrons. This is due to the condition of $v_T(i) < V_0 << v_T(e)$, where v_T (i) and v_T (e) are the thermal ion and electrons velocities and V_o is the spacecraft orbital velocity.

The interaction between the spacecraft and the plasma creates a wake that trails behind the body out to large distances. In this wake region, strong density depletions and enhancements are known to exist, depending on the downstream location. Electron temperature enhancements are also known to exist in the wake, but very little is known about the behavior of ion temperature in the wake.

It is the objective of the present paper to discuss the *ion* temperature characteristics in the wake of a body for two cases: (1) a spherical satellite attached by a tether to the shuttle Orbiter (TSS-1R mission) and (2) the Shuttle/Orbiter monitored by a free-flying sub-satellite (Spacelab-2 mission).

Experimental Conditions

The experimental set-up for Case 1, showing the probes and their locations on the TSS-satellite, is given in Figure 1. Further details on the probes are given in Dobrowolny and Stone (1994) and Stone et al. (1994). Note the location of the Differential Ion Flux Probe (DIFP) including its viewing geometry. Briefly, the DIFP is capable of deconvolving multiple, coincident ion streams that differ in flow direction and/or energy. More details on the DIFP are given in Stone (1977), Stone et al. (1985), and Stone et al. (1994). The DIFP was mounted on the Boom Mounted Sensor Package (BMSP) and faced the satellite such that an extension of the instrument axis always intersected the satellite spin axis.

In Case 2, a DIFP was mounted on a sub-satellite called the Plasma Diagnostic Package (PDP) (Stone et al., 1983). In addition, a planar RPA was mounted on the PDP (Reasoner et al., 1986). During part of the Spacelab-2 mission, the PDP was released as a free-flyer and the Orbiter made several maneuvers around the PDP. In effect, the PDP past through the wake of the Orbiter at several downstream positions located in the mid- and far-wake regions. We show data from the trajectory in which the maximum ion temperature enhancement was observed.

Discussion

The ion temperature, T_i (wake), results for Case 1 are shown in Figure 2. Data from eight wake crossing are overlaid in the plot. The standard, planar RPA equation (Whipple, 1959; Hanson et al., 1975) was used to fit the data through a non-linear least squares fit. A single ion mass (O^+) was used in the fit. This is a reasonable assumption since the altitude of the TSS-satellite was ~ 320 km and O^+ is the dominant ion at this altitude. The maximum enhancement of ion temperature, [T_i (wake) / T_i (ambient)], of approximately 1.8, occurred at a spin phase position of 180^0 (in the center of the wake). Note that for the data presented here, the tether current was zero and the satellite was, therefore, at floating potential.

The results for Case 2 are shown in Figure 3. This is a plot of ion temperature versus transverse position across the wake at a distance if approximately 105 m downstream from the Shuttle Orbiter. (This is a normalized distance of about 20 orbiter radii.)

The main issue of this paper is to emphasize the existence of an *ion* temperature enhancement in the wakes of ionospheric satellites. To date, the measurements presented here are the only ones that indicate such an enhancement. The measurements from the TSS-satellite were obtained at a distance of $2R_0$ downstream, whereas, the location downstream from the Orbiter where the maximum increase was observed is about $20R_0$. (R_0 is the physical radius of the wake-generating body.) The axial extent and variation of the [T_i (wake)] enhancement is still an open question because of the lack of available measurements in the wake region. The reader should note that data from both missions were obtained by the same probe and reduced by the same analysis technique—which lends credibility to the validity of the measurements.

The enhancement of electron temperature in the wake of an ionospheric satellite was first published in 1969 and was received at first with some skepticism—possibly as a result of the limited observations available at the time. Subsequently, this finding has been confirmed by data from a variety of missions. Theoretical modeling of the wake electron temperature enhancement was achieved in 1987. It is possible that the *ion* temperature enhancement, with its limited number of observations at the present time, resembles the situation with electrons in the past.

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Figures

Figure 1: (a) DIFP mounting arrangement on the TSS satellite. (b) The satellite body coordinate system is indicated by the X_B, Y_B, and Z_B axes and geometric reference for the DIFP ion stream angle measurements. (After: Stone et al., 1994.)

Figure 2: Data from the TSS-1R mission. The variation of T_i (eV) versus spin phase angle, where the maximum wake position is at 180°.

Figure 3: Data from the Spacelab-2 mission. Ion temperature variations with transverse distance from the wake axis at a distance of 20 R_o downstream. (Data obtained by the DIFP is shown as pluses, and by the RPA, as open circles.) (After: Sorensen et al. 1997.)